PB84-202225

Summary of GAC (Granular Activated Carbon) Research at Several Water Utilities

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

Jun 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-202225

EPA-600/D-84-146
June 1984

SUMMARY OF GAC RESEARCH AT SEVERAL WATER UTILITIES

by

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SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/D-84-146	2.	3. RECIPIENT'S ACCESSION NO. PB84 202225
4. TITLE AND SUBTITLE Summary of GAC Research at Several Water Utilities		5. REPORT DATE June 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ben W. Lykins, Jr. and Jeffrey Q. Adams		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Municipal Environmental Research Laboratory Drinking Water Research Division 26 W. St. Clair Cincinnati, OH 45268		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same as 9. above.		13. TYPE OF REPORT AND PERIOD COVERED Conference Proceedings
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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To provide adsorption efficiency data, considering the mix of compounds in drinking water sources and competition for available adsorption sites, granular activated carbon needed to be investigated in the field under actual operating conditions. Given this need, several large field scale research projects were initiated by the U.S. EPA Drinking Water Research Division, Cincinnati, Ohio to investigate the performance of GAC under varing operating conditions and different source water. Most of the GAC research effort has been completed at nine locations (Cincinnati, OH; Manchester, NH; Jefferson Parish, LA: Evansville, IN; Miami, FL; Huntington, WVA; Beaver Falls, PA; Passaic, NJ; and Thornton, CO).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 20
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

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Introduction

Granular activated carbon (GAC) has been in use for many years to remove taste and odors in drinking water. Within the past ten years, some utilities have seriously considered the use of GAC for removal of trace organics from their drinking water. With more sophisticated instrumentation rapidly becoming available that is affordable and useable by utilities, more organics at trace concentrations are being detected. Because the health effects of ingesting these trace concentrations of various organics over many years is unknown, utility managers as well as the general public are becoming more concerned.

To provide adsorption efficiency data, considering the mix of compounds in drinking water sources and competition for available adsorption sites, GAC needed to be investigated in the field under actual operating conditions. Given this need, several large field scale research projects were initiated by the U.S. EPA Drinking Water Research Division, Cincinnati, Ohio to investigate the performance of GAC under varing operating conditions and different source water. Most of the GAC research effort has been completed at nine locations (Cincinnati, OH; Manchester, NH; Jefferson Parish, LA: Evansville, IN; Miami, FL; Huntington, WV; Beaver Falls, PA; Passaic, NJ; and Thornton, CO).

GAC Systems

The GAC systems evaluated at each of the nine utilities are presented below.

- Cincinnati, OH
  - Pilot columns 3 to 4 in. in diameter with aggregate GAC depth of 2.5 to 15 ft.
  - Deep bed pressure contactors, 11 ft. in diameter and 22 ft. in height containing 15 ft. of GAC.
  - Sand replacement filters with 18 to 30 in. of GAC.
- Manchester, NH
  - GAC filters with 4 ft. of carbon.
- Jefferson Parish, LA
  - Pilot columns 3 in. in diameter with 30 to 36 in. of GAC.
  - GAC filter with 30 in. of carbon.
  - Sand replacement filters with 24 to 30 in. of GAC.

- Evansville, IN - Pressure contactors 38 in. in diameter and 9 ft. in height with 6.5 ft. of GAC.
- Miami, FL - Bench-scale columns 1 in. in diameter and 5 ft. in height with 30 in. of GAC.
- Huntington, WV - Sand replacement filters with 30 in. of GAC.
- Beaver Falls, PA - Sand replacement filters with 24 in. of GAC.
- Passaic, NJ - Pressure contactors 8 ft. in diameter and 28 ft. in height with 19.5 ft. of GAC.
- Thornton, CO - Pilot columns 6 in. in diameter and 8 ft. in height with 5.5 ft. of GAC.

Virgin GAC Performance

Various carbons produced for organics removal were evaluated at the nine locations. The major reason for selecting a particular GAC was economic, wherein a low bidder was chosen. There were, however, occasions when a GAC was selected that had not been previously evaluated. Also, for a few projects, a GAC was selected based on performance when evaluated in parallel with various other GACs.

Overall, around 160 specific organic compounds were in the total analytical schemes of the utilities. All of these compounds, however, were not detected. In addition to these specific organics, surrogate parameters such as total organic carbon (TOC) and total organic halide (TOX) were used in many cases to determine GAC performance.

The use of gas chromatography/flame ionization detection (GC/FID) capillary column profiles to visually demonstrate the effectiveness of GAC for removal of organics was useful. This method was used at Cincinnati as an indicator of GAC performance. As shown in Figure 1, the sand filter effluent as applied to the GAC contactor contained several organics identified by this method. After 29 days of GAC treatment, most of these organics were completely removed or reduced in concentration.

Specific organic compounds were also effectively removed by GAC. For instance, in Jefferson Parish, the most prevalent low molecular weight specific organic other than the trihalomethanes was 1,2-dichloroethane. Although the normal treatment process did not reduce the concentration of this compound, GAC continued to provide removal up to 100 days of operation (Figure 2).

Another prevalent compound in the water at Jefferson Parish was atrazine. This chlorinated herbicide, like 1,2-dichloroethane, was not reduced in concentration during conventional treatment. Raw water concentrations varied relative to water temperature and seasonal effects. The GAC adsorber effectively removed atrazine to below detection limits (0.98 ng/L) and no desorption occurred up to 180 days of operation (Figure 2).

GAC has been shown to be an effective barrier against organic spillage in surface waters. An example was Cincinnati where five specific organic compounds were evaluated for four months. Using the GROB closed-loop stripping method, some of these compounds were not detected at the beginning of a GAC test period (Table 1). After four months of operation, however, influent concentrations of all five compounds had increased dramatically but the GAC removed them completely.

At most locations, with TOC as an evaluation criteria, three months would generally be expected to be the service life of GAC before replacement or reactivation. At these locations TOC and TOX concentrations were reduced during conventional treatment. The GAC, however, further reduced their concentration. For example, average concentrations for a six month run at Thornton, CO are shown in Table 2.

GAC Adsorber vs Filter-Adsorber

At three locations (Cincinnati, Jefferson Parish, and Thornton) both the post-sand filter adsorber and the sand replacement adsorber (filter-adsorber) were evaluated. At Cincinnati an empty bed contact time (EBCT) at the midpoint of the adsorber was selected to coincide with the EBCT of the filter-adsorber which was 7.2 and 7.5 minutes, respectively. The performance of these two systems was comparable as shown by the percent TOC removal (Figure 3).

Maintenance of exact operating conditions for comparative purposes is difficult in any full-scale project. This was the case at Jefferson Parish. Although the EBCT for the filter-adsorber was longer at 23.2 minutes vs. 18.8 minutes for the adsorber, the TOC performance was essentially the same (Figure 3).

By using the pilot plant at Thornton for evaluation of the GAC adsorber and filter-adsorber, a consistent EBCT could be maintained for both. With an EBCT of 20 minutes for each adsorption system, one can see from the average concentrations presented in Figure 3 that for all modes evaluated, the filter adsorber effluent concentration for TOC was lower than for the adsorber effluent. This occurred although the average applied concentration was similar.

Pilot vs Full-Scale GAC Systems

The ability to predict full-scale GAC performance from pilot systems provides utilities with an economical screening mechanism to use before making decisions relative to GAC use. Generally, the pilot system at Cincinnati predicted the full-scale adsorber performance for up to about 150 days of operation although there were some discrepancies (Figure 4). For all evaluations at Cincinnati, the full-scale adsorber was more efficient for percent removal of TOC than the corresponding pilot column although the hydraulic loading and EBCTs were similar. Essentially identical TOC removals were seen for the pilot and full-scale filter-adsorber systems.

At Jefferson Parish, predictive performance was generally similar with the pilot column simulators of the full-scale systems. The EBCTs were somewhat different between the pilot and full-scale systems although the hydraulic loadings were similar. This difference is reflected in an average of about 8 percent more TOC removed by the pilot adsorber (Figure 4). The pilot filter adsorber removed up to an average of 13 percent more TOC than the sand replacement bed again with similar hydraulic loadings and somewhat different EBCTs. Similar pilot column predictive capabilities were noted for specific organics such as 1,2-dichloroethane.

Effects of EBCT

The length of GAC operation before replacement or reactivation depends on several factors, one of which is EBCT. If a utility is required to use existing filters, very little flexibility is available for selection of EBCT. In designing a new system, however, the utility has an opportunity to determine the best EBCT relative to performance criteria and cost.

A GAC exhaustion criteria of 1.0 mg/L TOC was selected by Cincinnati as a reasonable performance standard. Exhaustion was determined after the 1.0 mg/L criteria had been exceeded for three consecutive sampling days. By using this criteria, the performance effects of varying EBCTs at three locations were examined.

By evaluating various points along the contactors at Cincinnati, one can see in Table 3 that increased EBCT up to 15.2 minutes provided more efficient use of the GAC. By extending the EBCT far beyond 15 minutes at Jefferson Parish and using the same type of GAC, one can now see a longer operational time with increased EBCT through 31.4 minutes. Above that EBCT no apparent advantage was gained by additional contact time although some improvement in GAC effluent quality was noted.

Another example of diminishing returns after the most efficient EBCT has been determined was shown in the research project at Miami, FL. The finished water TOC concentration before GAC adsorption at Miami was about 5 mg/L as compared to Cincinnati and Jefferson Parish ranges of 2 to 4 mg/L. At this location, the carbon was exhausted in a very short time even at an extended EBCT of about 25 minutes (Table 3). Actually, little advantage was gained after about 6 minutes EBCT.

GAC Reactivation

GAC was reactivated on-site at three field locations (Cincinnati, Manchester, and Passaic) and off-site at one other location (Evansville). The two different types of units that were used for reactivation were the fluidized-bed and infrared furnace. A 500 lb/hr fluidized-bed furnace was used at Cincinnati and Manchester. For reactivating spent GAC at Passaic and Evansville, a 100 lb/hr infrared unit was used.

Several GAC properties were evaluated to ensure that proper reactivation had occurred. One of the easier properties to determine that is widely

accepted as an immediate indication of the efficiency of the reactivation process was the apparent density. As shown in Table 4, this property indicated that for both furnace types, the spent GAC was essentially restored to the virgin state.

The ideal approach for determining the effects of reactivation is to evaluate the adsorbent performance of subsequently reactivated to virgin GAC using parallel systems so that the same influent is applied to both. This was only possible in Evansville with the other locations evaluating their systems at different time periods with GAC influent variations such as temperature, water quality, etc. When looking at performance, however, organic loading was often used for comparative purposes to normalize the varying influent concentrations and GAC weights.

The performance of the GAC as determined by the loading was comparable for virgin and subsequently reactivated GAC at Cincinnati (Figure 5). The same general trend was seen for Evansville through two reactivations (Figure 5). These loading curves indicate that the TOC concentration was better removed at Cincinnati possibly because of the type of carbon used (coal- vs lignite-base).

From an economic standpoint, the most important GAC operational criteria to consider is carbon losses resulting from reactivation and transport. Total average losses (by volume) for the GAC adsorbers ranged from 8 percent for the infrared furnace to 15 percent for the fluidized bed furnace (Table 4).

Because various organic compounds are adsorbed by GAC, there has been a concern about the possible discharge into the atmosphere of these organics or their byproducts. Furnace off-gas analyses were performed at Cincinnati and Manchester during the research effort without identification of any problem. As an additional effort at Cincinnati, several effluent streams were tested for the possible presence of tetrachlorodibenzo-p-dioxins (TCDDs) or tetrachlorodibenzo furans (TCDFs). The GAC used for this study had been in service for about one year and was stored in the contactor for about six months before reactivation. Table 5 shows that both TCDDs and TCDFs were detected in low concentrations.

Since less than detectable concentrations of TCDDs or TCDFs were seen in the spent carbon, indications are that they were formed in the furnace. Precursors for their formation at Cincinnati are unknown. Chlorinated compounds such as trichlorophenols are a possibility. Another possible precursor could be PCBs that were detected in the natural gas used to fire the furnace. At the time of testing, PCB concentrations in the natural gas were 2.2 ppb.

A risk assessment of the reactivation furnace stack emission discharge stated that there was no evidence of a health concern. This risk assessment was done using a worst case situation of an individual at the point of maximum annual concentration, exposed 24 hours per day for 70 years, under the worst atmospheric conditions. Although the risk assessment indicated that there was not a health concern, an additional study will be done at Cincinnati after treatment and furnace modifications have been completed to eliminate any TCDD or TCDF dishcarges.

GAC Treatment Costs

Actual cost data associated with the construction and operation of full-scale research facilities at Cincinnati and Manchester have been summarized. In addition, cost estimates for various GAC treatment scenarios have been developed to examine the effect of economies of scale and cost tradeoffs among alternative GAC treatment systems. Some of the conclusions from this evaluation are presented below.

- Concrete gravity GAC contactor systems appear to exhibit lower total water production costs (adsorption plus reactivation) than steel pressure GAC contactor systems given the same water quality goal. Steel pressure contactors ranged from about 50¢/1000 gal for a 3 mgd plant using infrared reactivation to about 23¢/1000 gal for a 175 mgd plant using fluid-bed reactivation. Concrete gravity contactors ranged in cost from about 41¢/1000 gal for a 3 mgd plant with infrared reactivation to about 17¢/1000 gal for a 175 mgd plant with fluid-bed reactivation.

- The Cincinnati study showed that a full-scale deep-bed steel pressure GAC contactor system appears to be more economical than a conventional-depth sand replacement GAC system.

- Infrared reactivation appears to be more economical than fluid bed and multihearth reactivation for small quantities of carbon. For quantities of carbon greater than about 2,000,000 lbs/year, fluid bed reactivation appears to be most cost effective.

- On-site reactivation appears to be more economical than replacement of spent carbon with virgin GAC for amounts of carbon as small as 300,000 lbs/year.

Summary

Major waterways such as the Ohio and Mississippi Rivers contain many hundreds of trace organics in the ng/L range. Because of the unknown effects of ingesting these trace organics over many years, the general public is placing pressure both directly and indirectly on the utility managers to remove them from drinking water. GAC has been shown to be a broad spectrum adsorbent that can remove most of these organics cost-effectively.

Metric Conversions

in x 2.54 = cm
ft x 0.3048 = m
lb/hr x 0.454 = kg/hr
¢/1,000 gal x 0.2642 = ¢/1,000L
mgd x 0.0438 = m^3/sec
lb/yr x 0.454 = kg/yr
gpm/ft^2 x 2.445 = m^3/hr/m^3

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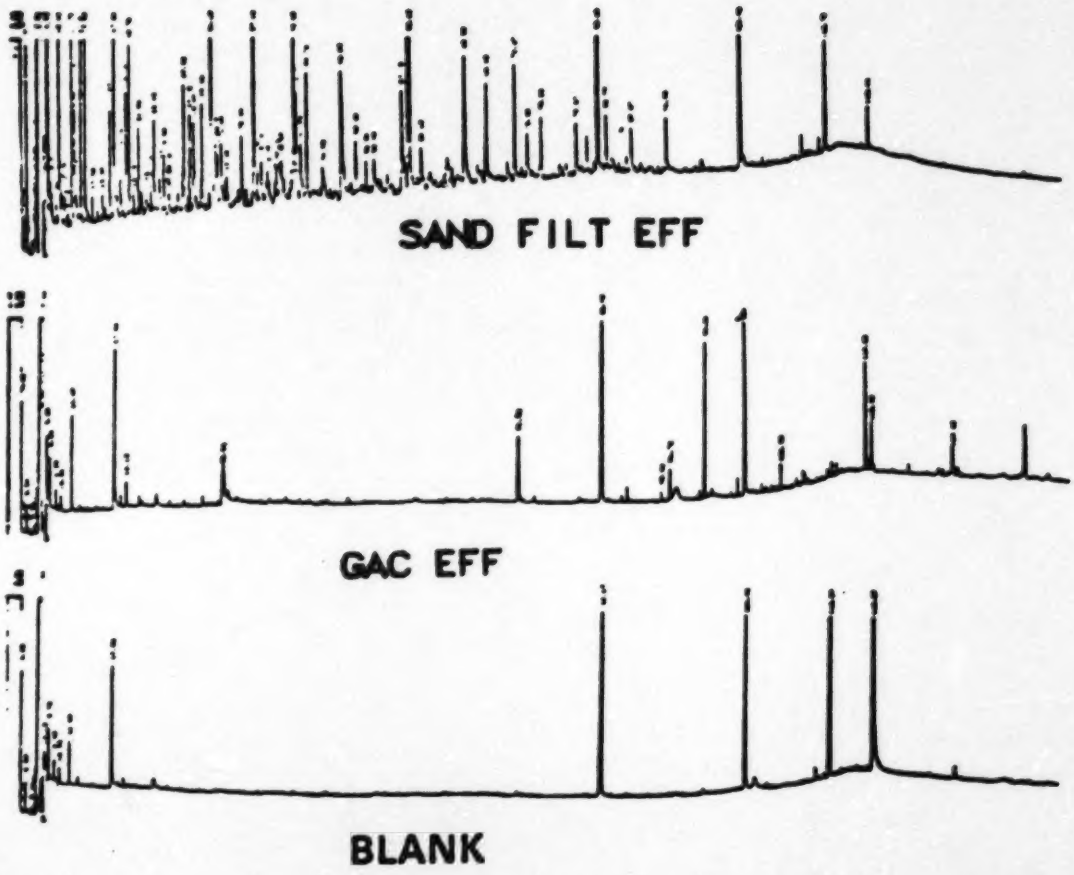


FIGURE 1 GC/FID CAPILLARY COLUMN PROFILES AFTER 29 DAYS OF OPERATION – CINCINNATI, OHIO

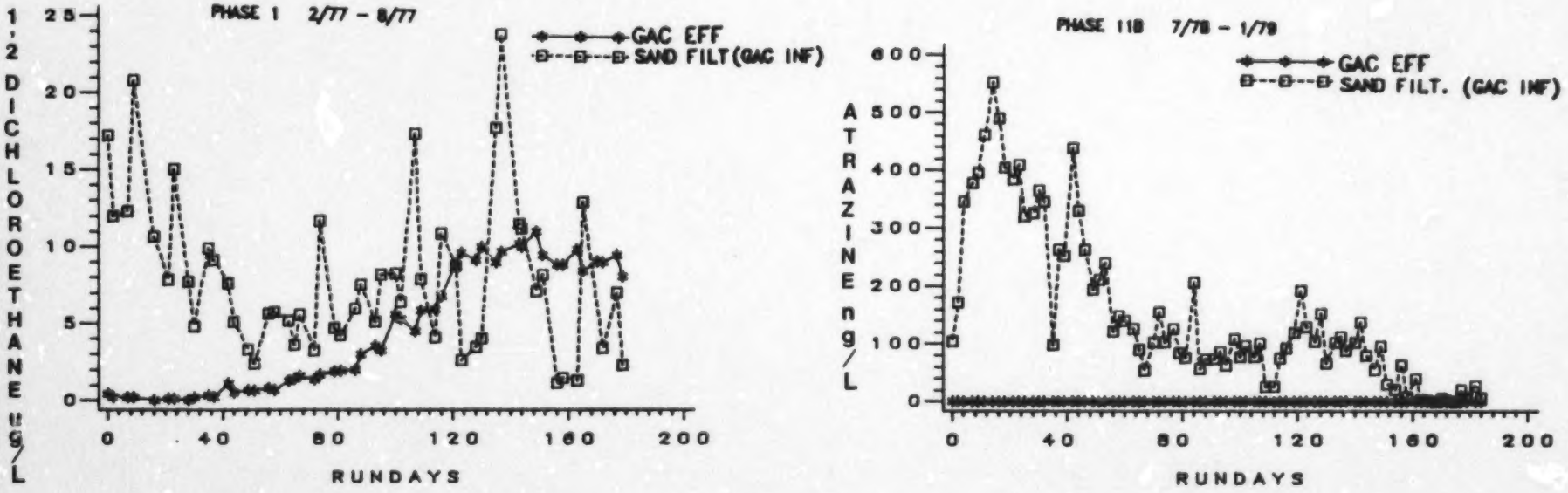


FIGURE 2 REMOVAL OF SPECIFIC ORGANICS BY GAC
JEFFERSON PARISH, LA

TABLE 1. MEAN VALUES OF CINCINNATI, OHIO GAC STUDY

GROB CLOSED-LOOP STRIPPING (ng/L)

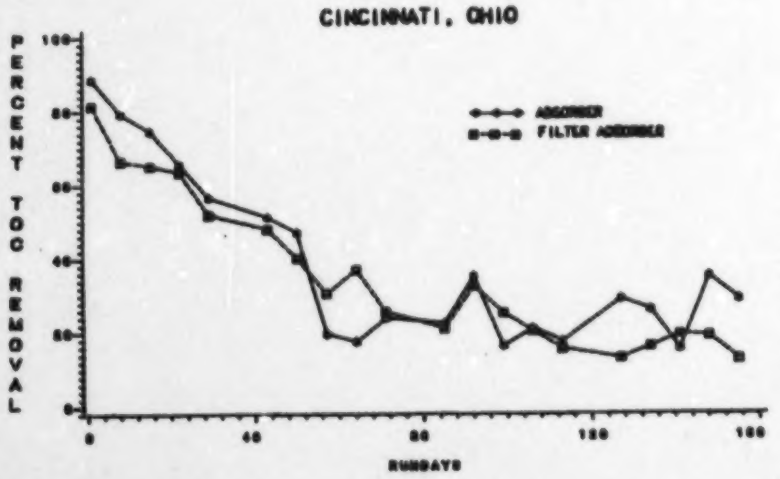
Compounds	Run Time (months) 0		1		2		3		4	
	Inf.	% Removed	Inf.	% Removed	Inf.	% Removed	Inf.	% Removed	Inf.	% Removed
Benzene	ND		9.8	100	ND		28.1	100	843	100
Carbon Tetrachloride	4.0	100	58	94	2.7	93	8.9	100	43	100
Trichloroethene	ND		16	98	4.2	98	5.7	100	26	100
Tetrachloroethene	9.0	100	23	100	20	98	7.5	100	34	100
Chlorobenzene	ND		1.4	100	2.6	92	12	100	62	100

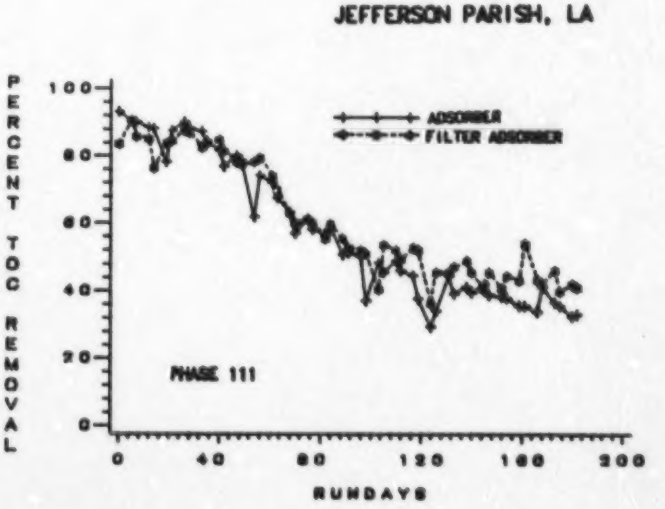
ND - Not Detected

TABLE 2. SIX MONTH AVERAGE CONCENTRATIONS FOR TOC AND TOX AT THORNTON, CO

	Raw Water	Pilot Plant Filter Effluent	GAC Adsorber Effluent
TOC, mg/L	5.1	4.1	1.3
Inst TOX, ug/L	92	464	128
Term TOX, ug/L(1)	597	475	266

(1) Stored 5-days with free Cl_2 residual, pH 8.0, ambient temperature.





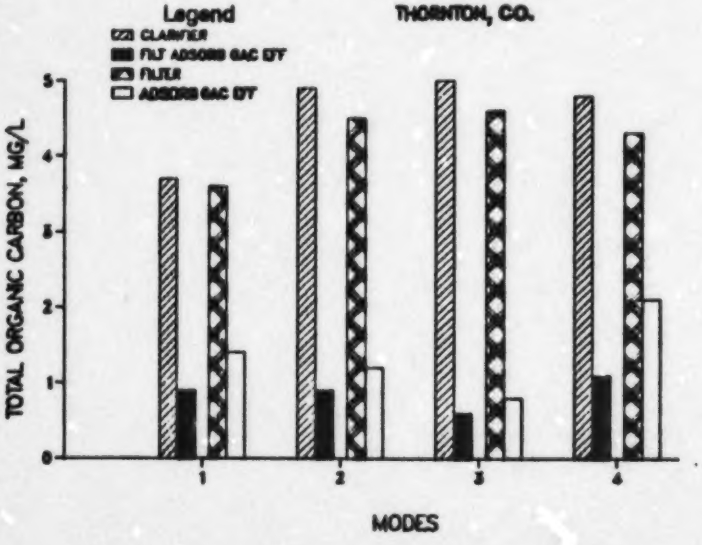


FIGURE 3 COMPARISON OF TOC PERFORMANCE FOR ADSORBER AND FILTER ADSORBER

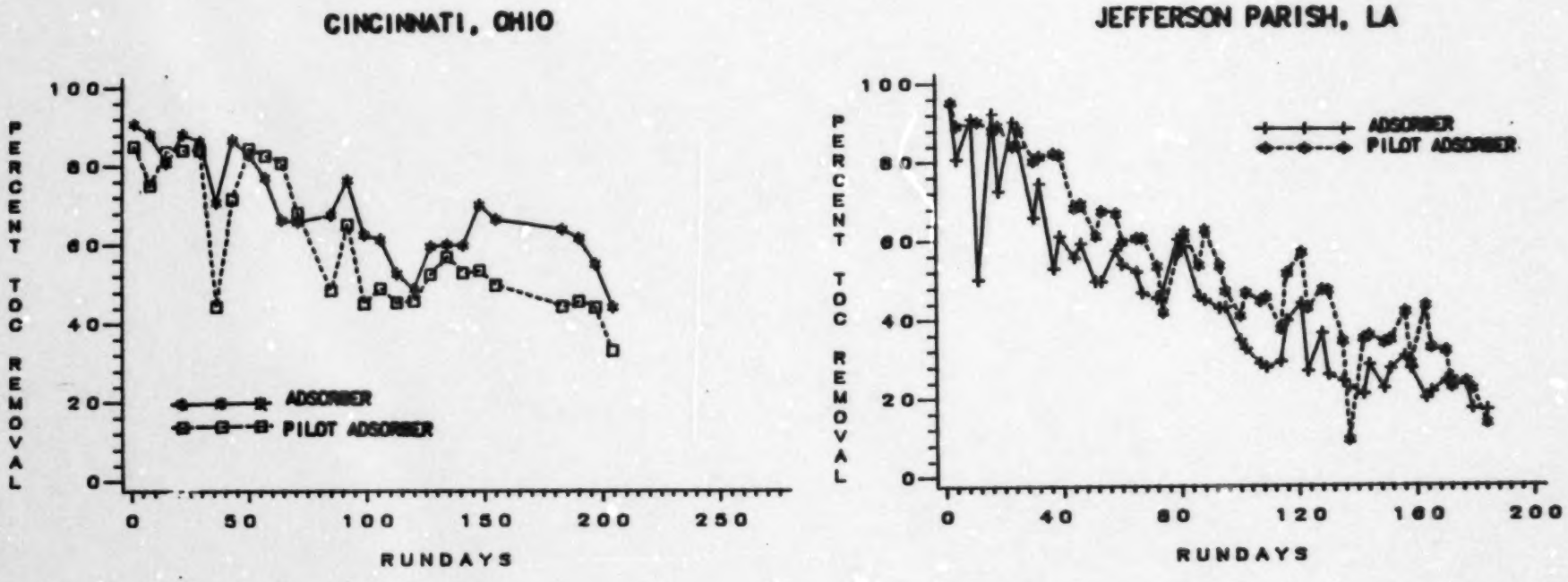


FIGURE 4 PREDICTION OF ADSORBER PERFORMANCE FOR TOC USING PILOT SIMULATION

TABLE 3. SUMMARY DATA OF GAC EXHAUSTION AT 1.0 mg/L TOC

GAC Depth (ft)	EBCT (Minutes)	Hydraulic Loading (gpm/ft^2)	TOC Exhaustion Time (Days)	Carbon Use Rate ($Kg/L \times 10^6$)	Organic Loading mg/kg
VIRGIN WVG® 12x40 GAC - CINCINNATI, OH					
4.3	4.4	7.4	22	46	0.015
7.0	7.2	7.4	71	34	0.025
15.0	15.2	7.4	204	26	0.051
VIRGIN WVG® 12x40 GAC - JEFFERSON PARISH, LA					
3	10.4	2.2	30	94	0.031
6	20.9	2.2	79	36	0.070
9	31.4	2.2	106	27	0.103
12	41.8	2.2	106	27	0.109
VIRGIN F400® GAC - MIAMI, FL					
2.5	6.2	3.0	21	92	0.023
5.0	12.4	3.0	21	92	0.039
7.5	18.6	3.0	28	69	0.060
10.0	24.8	3.0	35	35	0.078

TABLE 4. EFFECTS OF GAC REACTIVATION

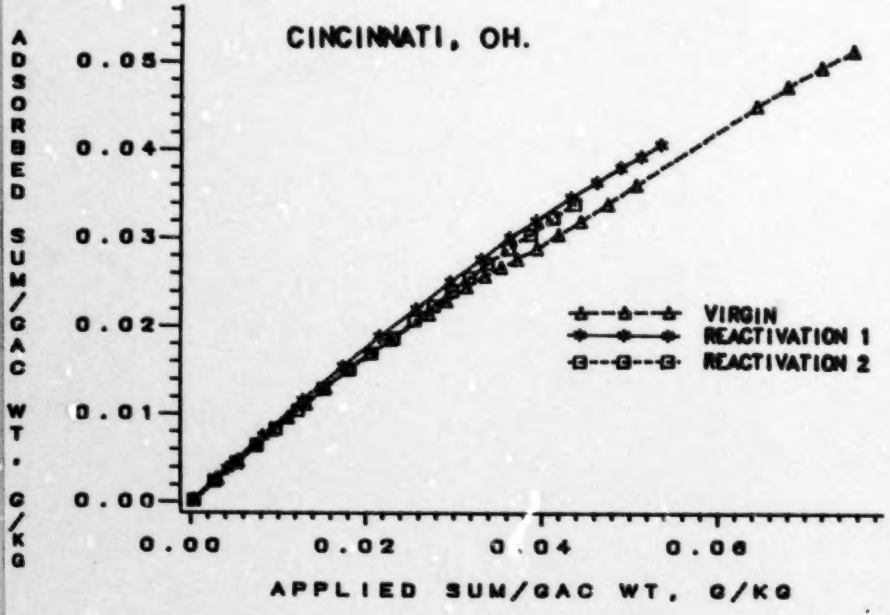
Apparent Density (g/mL) of Reactivated GAC

Furnace Type	Virgin GAC	Subsequent Reactivations 1	2	3	4
Fluidized bed					
Cincinnati, OH[1]	0.48	0.48	0.47	0.47	0.52
Manchester, NH[2]	0.61	0.59	0.58	0.56	-
Infrared					
Evansville, IN[3]	0.43	0.45	0.40	0.44	-
Passaic, NJ					
WVW® 12 x 40	0.58	0.57	0.58	0.59	
F400®	0.47	0.49	0.49	0.50	
HD® 10 x 30	0.44	0.43	0.43	0.43	

Average Percent GAC Loss, By Volume

Furnace Type	Transport	Reactivation	Total
Fluidized bed			
Cincinnati, OH[1]	3.1	12.2	15.3
Manchester, NH[2]	2.0	10.9	12.9
Infrared			
Evansville, IN[3]	3.0	5.0	8.0

[1] WVW® 12 x 40
[2] F400® 8 x 30
[3] HD® 10 x 30



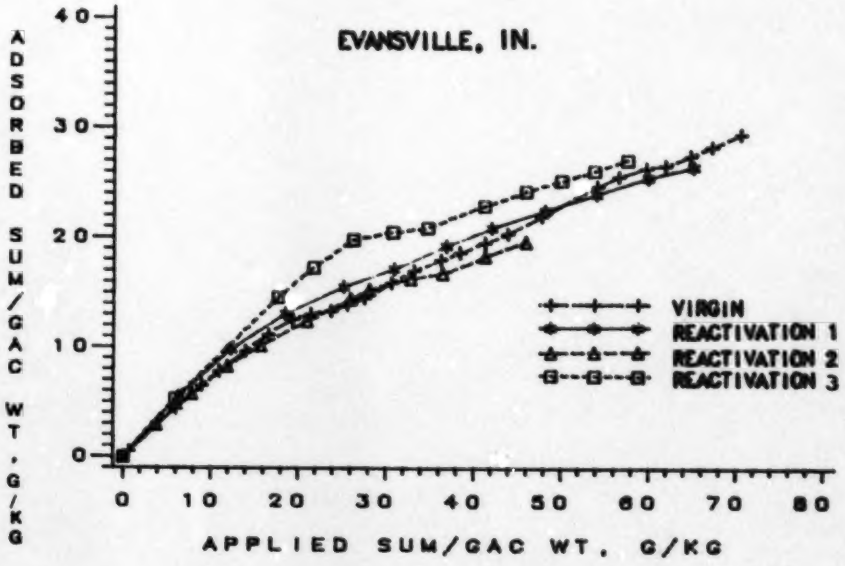


FIGURE 5 TOC LOADING FOR SUBSEQUENTLY REACTIVATED GAC

TABLE 5. AVERAGE CONCENTRATIONS OF TCDD AND TCDF IN CINCINNATI, OHIO GAC REACTIVATION SAMPLES

Sample	2,3,7,8-TCDD[1]	TOTAL TCDD[1]
Spent GAC Feed, ppb	<0.05	<0.1
Cyclone Catch, ppb	<0.04	2.21
Scrubber Liquid, ppt	0.03	0.08
Quench Water, ppt	<0.05	<0.1
Stack Gas, ppt		
(Particulate Contribution)	0.08	0.13
(Volatile Contribution)	<0.01	0.01

Sample	2,3,7,8-TCDF[1]	TOTAL TCDF[1]
Spent GAC Feed, ppb	<0.07	<0.14
Cyclone Catch, ppb	0.87	1.68
Scrubber Liquid, ppt	<0.05	<0.1
Quench Water, ppt	<0.06	<0.12
Stack Gas, ppt		
(Particulate Contribution)	0.06	0.21
(Volatile Contribution)	<0.02	0.04

(1) Average of four tests